US009226240B2

(12) **United States Patent**
Gong et al.

(10) **Patent No.: US 9,226,240 B2**
(45) **Date of Patent: Dec. 29, 2015**

(54) **POWER MANAGEMENT FOR WIRELESS NETWORKS**

(71) Applicant: **Intel Corporation**, Santa Clara, CA (US)

(72) Inventors: **Xiaohong Gong**, Sunnyvale, CA (US); **Jesse Walker**, Portland, OR (US)

(73) Assignee: **INTEL CORPORATION**, Santa Clara, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **14/094,666**

(22) Filed: **Dec. 2, 2013**

(65) **Prior Publication Data**

US 2014/0086129 A1 Mar. 27, 2014

Related U.S. Application Data

(63) Continuation of application No. 13/480,515, filed on May 25, 2012, which is a continuation of application No. 12/317,099, filed on Dec. 19, 2008, now Pat. No. 8,203,984.

(51) **Int. Cl.**

H04W 52/02	(2009.01)
H04W 52/54	(2009.01)
H04W 84/18	(2009.01)
G06F 1/32	(2006.01)
H04W 76/04	(2009.01)

(52) **U.S. Cl.**

CPC ***H04W 52/0235*** (2013.01); ***G06F 1/3209*** (2013.01); ***G06F 1/3228*** (2013.01); ***H04W 52/0216*** (2013.01); ***H04W 76/048*** (2013.01); *H04W 84/18* (2013.01); *Y02B 60/50* (2013.01)

(58) **Field of Classification Search**

CPC H04W 84/18; H04W 52/0216; H04W 52/0235; G06F 1/3228; Y02B 60/50

USPC 370/311, 312; 455/343.2, 343.4

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

7,369,518	B2 *	5/2008	Lee	370/311
7,522,547	B2 *	4/2009	Lee et al.	370/312
7,551,948	B2	6/2009	Meier et al.	
7,697,457	B2 *	4/2010	Igarashi et al.	370/254

(Continued)

FOREIGN PATENT DOCUMENTS

JP 2008060934 3/2008

OTHER PUBLICATIONS

Office Action received for Japanese Patent Application No. 2013-097182, mailed Jul. 1, 2014, 6 pages including 3 pages English translation.

Kneckt et al., "Power save for 802.11s", IEEE P802.11 Wireless LANs, Jan. 16, 2008, IEEE 802.11-08/0168r1, URL: https://mentor.ieee.org/802.11/dcn/08/11-08-0168-01-000s-combined-power-save-normative-text.doc, 10 pages.

(Continued)

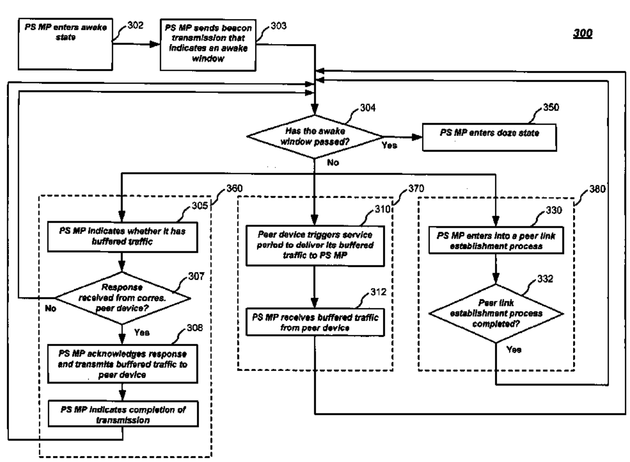
Primary Examiner — Ahmed Elallam

(74) *Attorney, Agent, or Firm* — Kacvinsky Daisak Bluni PLLC

(57) **ABSTRACT**

Embodiments provide techniques for device power management in wireless networks. For instance, an apparatus may include a power management module, and a transceiver module. The power management module determines a beacon interval and a wakeup interval. The transceiver module to send a transmission to one or more remote devices that includes the beacon interval and the wakeup interval. The beacon interval indicates a time interval between consecutive beacon transmissions of the apparatus, and the wakeup interval indicates a time interval between when the apparatus receives two consecutive beacons from a peer device.

20 Claims, 9 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

8,203,984	B2 *	6/2012	Gong et al.	370/311
8,295,216	B2 *	10/2012	Jokela	370/311
8,355,380	B1 *	1/2013	Banerjea	370/331
8,675,620	B1 *	3/2014	Benveniste	370/338
9,088,946	B2 *	7/2015	Wentink	
2005/0221869	A1 *	10/2005	Liu et al.	455/574
2006/0285527	A1 *	12/2006	Gao et al.	370/338
2007/0242634	A1 *	10/2007	Calcev et al.	370/318
2007/0281658	A1 *	12/2007	Chou	455/343.2
2008/0037570	A1 *	2/2008	Kim et al.	370/406
2008/0225768	A1	9/2008	Wentink	
2008/0226071	A1	9/2008	Braskich et al.	
2009/0010190	A1 *	1/2009	Gong	370/311
2009/0067373	A1 *	3/2009	Kneckt et al.	370/328
2009/0097428	A1 *	4/2009	Kneckt et al.	370/311
2009/0122755	A1	5/2009	Seok et al.	
2009/0147714	A1 *	6/2009	Jain et al.	370/311
2009/0196211	A1 *	8/2009	Wentink	370/311
2009/0225731	A1 *	9/2009	Kneckt et al.	370/338
2009/0232042	A1 *	9/2009	Kneckt et al.	370/312
2009/0232119	A1	9/2009	Seok	
2009/0268652	A1 *	10/2009	Kneckt et al.	370/311
2009/0274083	A1 *	11/2009	Wentink	370/311
2009/0279449	A1 *	11/2009	Kneckt et al.	370/253
2012/0176949	A1 *	7/2012	Meylan et al.	370/311

OTHER PUBLICATIONS

Kneckt et al., "Power save for 802.11s", IEEE P802.11 Wireless LANs, Jul. 15, 2008, IEEE 802.11-08/0757r3 URL: https://mentor.ieee.org/802.11/dcn/08/11-08-0757-03-000s-power-save-for-80211s.doc, 11 pages.

Kneckt et al., "Normative Text for Power Save", IEEE P802.11Wireless LANs, Sep. 8, 2008, IEEE 802.11-08/1057r0, URL: https://mentor.ieee.org/802.11/dcn/08/11-08-1057-00-000s-normative-text-for-power-save. doc, 5 pages.

Office Action received for Japanese Patent Application No. 2013-097182, mailed Mar. 11, 2014, 4 pages including 2 pages English translation.

Sakoda, Kazuyuki, "Suggested comment resolution on ATIM window parameter", IEEE P802.11, Wireless LANs, Mar. 14, 2007, 13 pages.

Office Action received for Chinese Patent Application No. 200980139209.3, mailed Mar. 10, 2014, 8 pages English translation.

European Search Report received for European Patent Application No. 14155059.0, mailed Mar. 10, 2014, 6 pages.

Office Action received for U.S. Appl. No. 13/480,515, mailed Feb. 4, 2015, 8 pages.

Notice of Allowance received for U.S. Appl. No. 13/480,515, mailed Jun. 8, 2015, 8 pages.

* cited by examiner

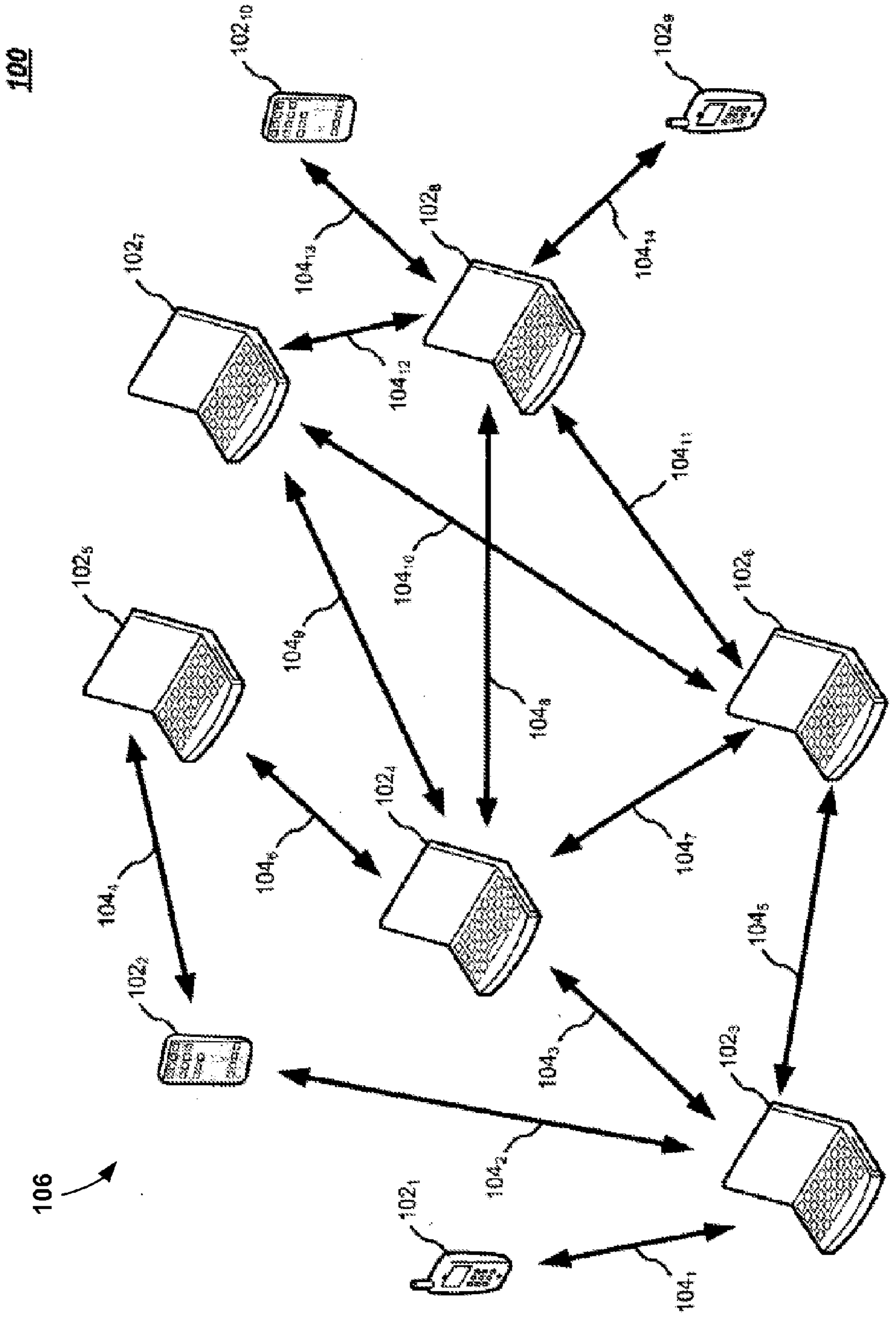

100
106
102_1
102_2
102_3
102_4
102_5
102_6
102_7
102_8
102_9
102_{10}
104_1
104_2
104_3
104_4
104_5
104_6
104_7
104_8
104_9
104_{10}
104_{11}
104_{12}
104_{13}
104_{14}

FIG. 1

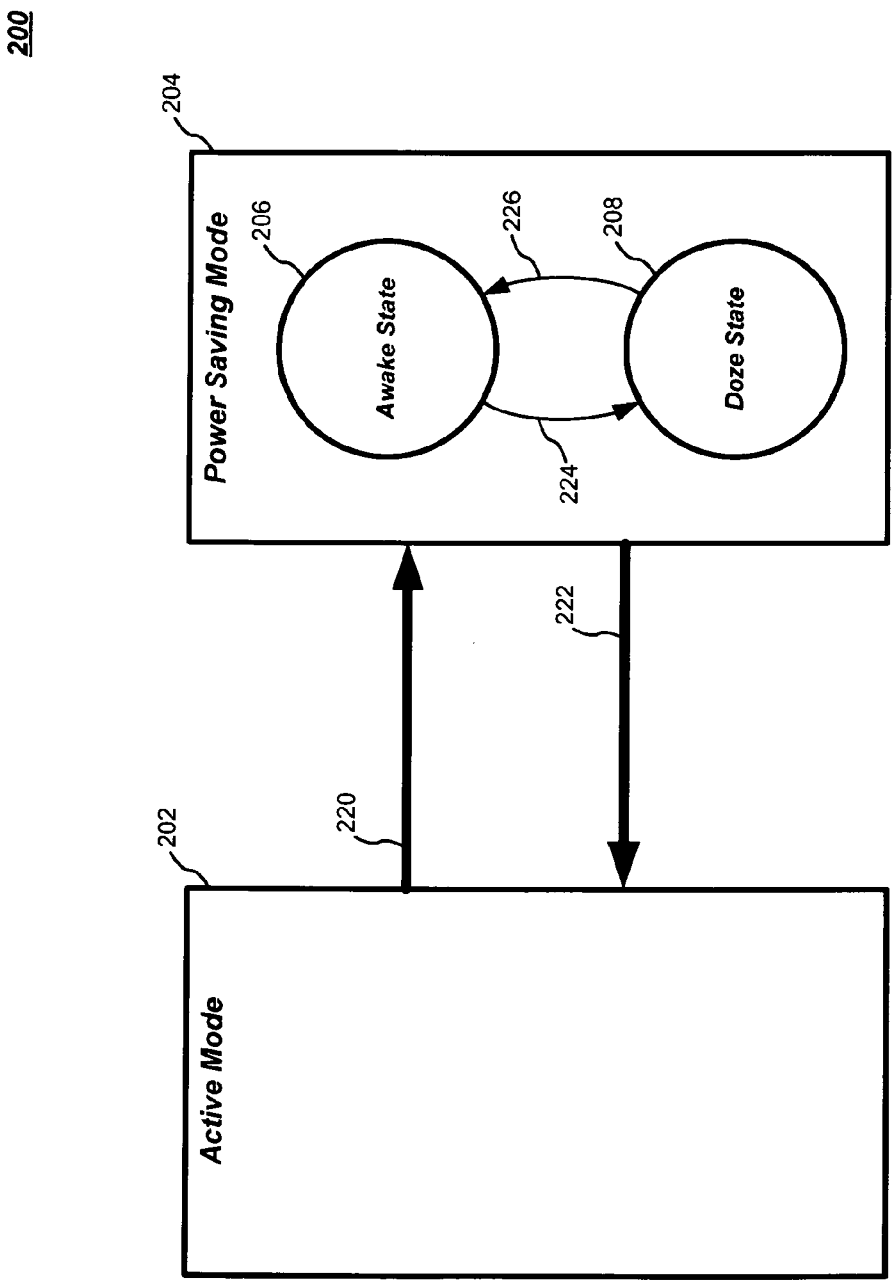

200
204
Power Saving Mode
206
Awake State
226
208
Doze State
224
222
220
202
Active Mode

FIG. 2

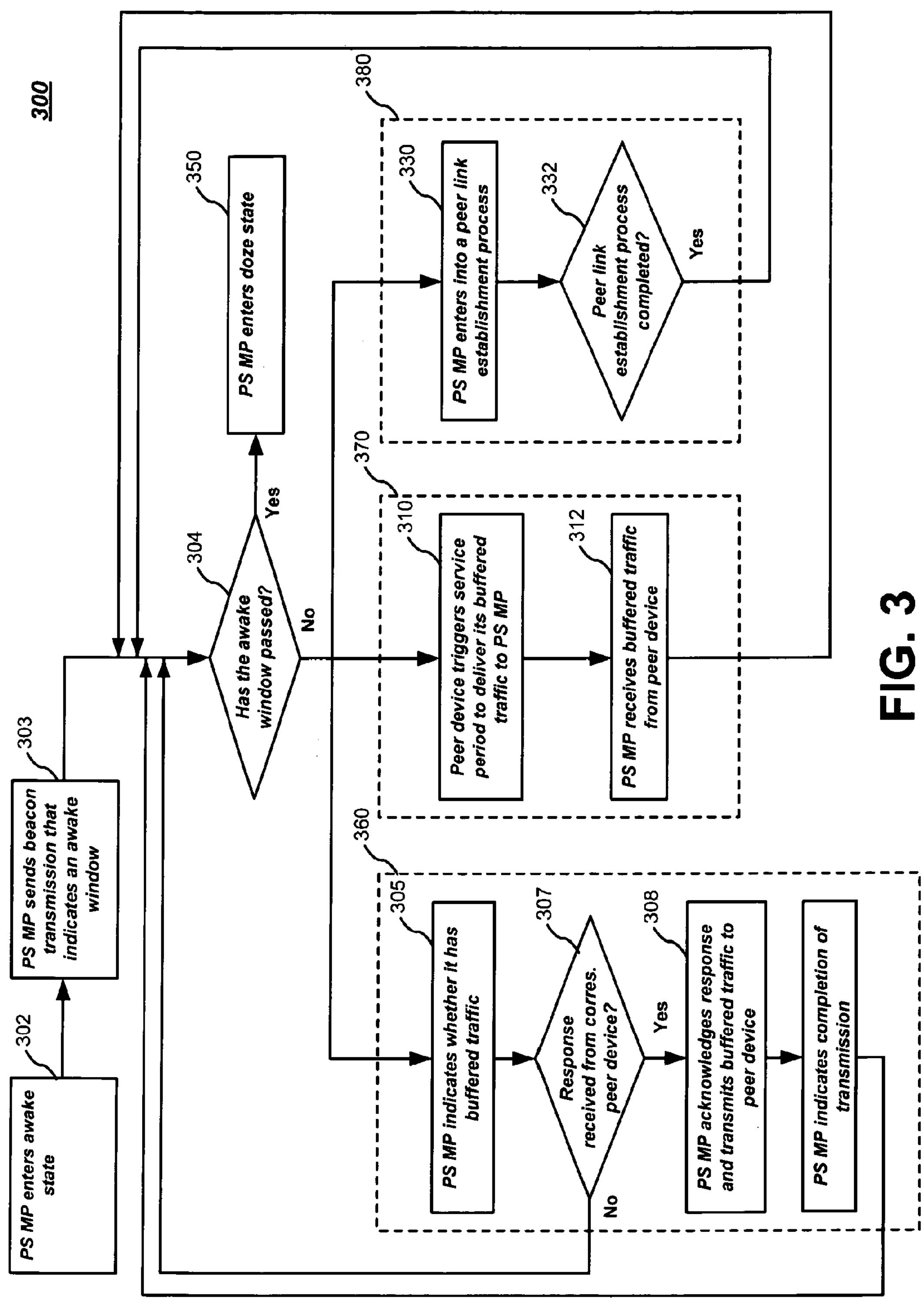

300
302
PS MP enters awake state
303
PS MP sends beacon transmission that indicates an awake window
304
Has the awake window passed?
Yes
No
350
PS MP enters doze state
380
330
PS MP enters into a peer link establishment process
332
Peer link establishment process completed?
Yes
370
310
Peer device triggers service period to deliver its buffered traffic to PS MP
312
PS MP receives buffered traffic from peer device
360
305
PS MP indicates whether it has buffered traffic
307
Response received from corres. peer device?
Yes
No
308
PS MP acknowledges response and transmits buffered traffic to peer device
PS MP indicates completion of transmission

FIG. 3

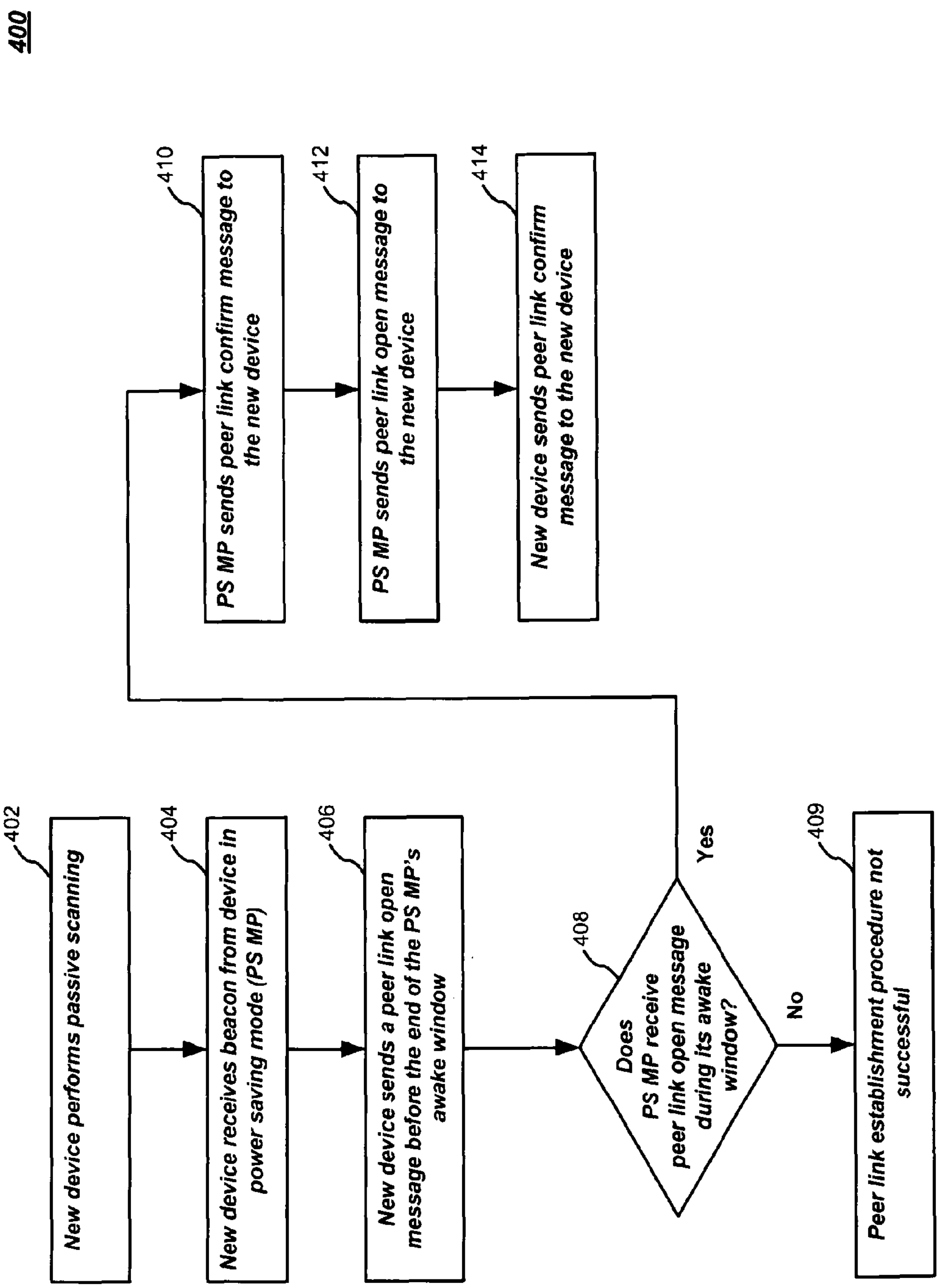

400
402
New device performs passive scanning
404
New device receives beacon from device in power saving mode (PS MP)
406
New device sends a peer link open message before the end of the PS MP's awake window
408
Does PS MP receive peer link open message during its awake window?
Yes
No
409
Peer link establishment procedure not successful
410
PS MP sends peer link confirm message to the new device
412
PS MP sends peer link open message to the new device
414
New device sends peer link confirm message to the new device

FIG. 4

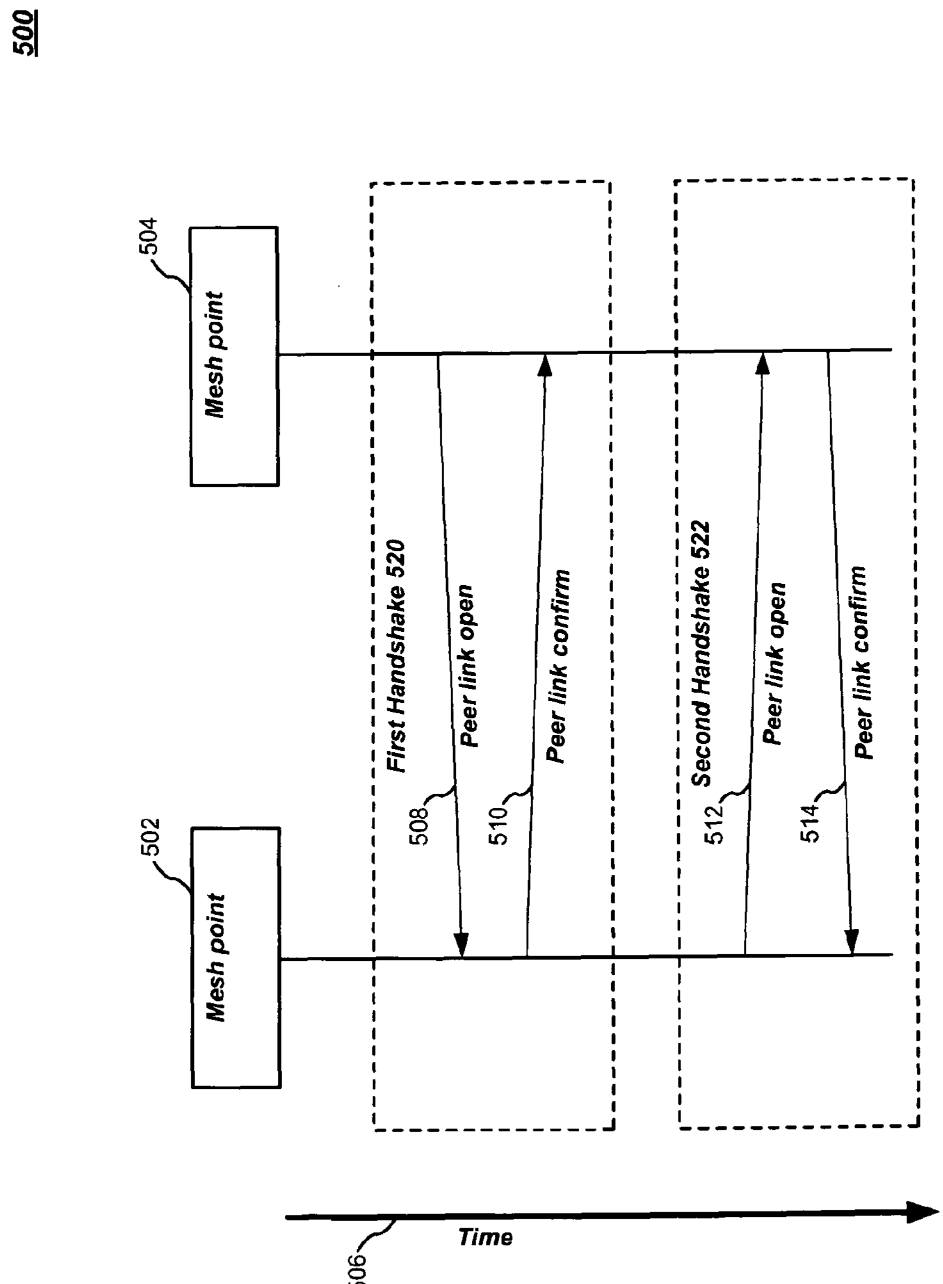

500
504
Mesh point
502
Mesh point
First Handshake 520
Peer link open
508
Peer link confirm
510
Second Handshake 522
Peer link open
512
Peer link confirm
514
Time
506

FIG. 5

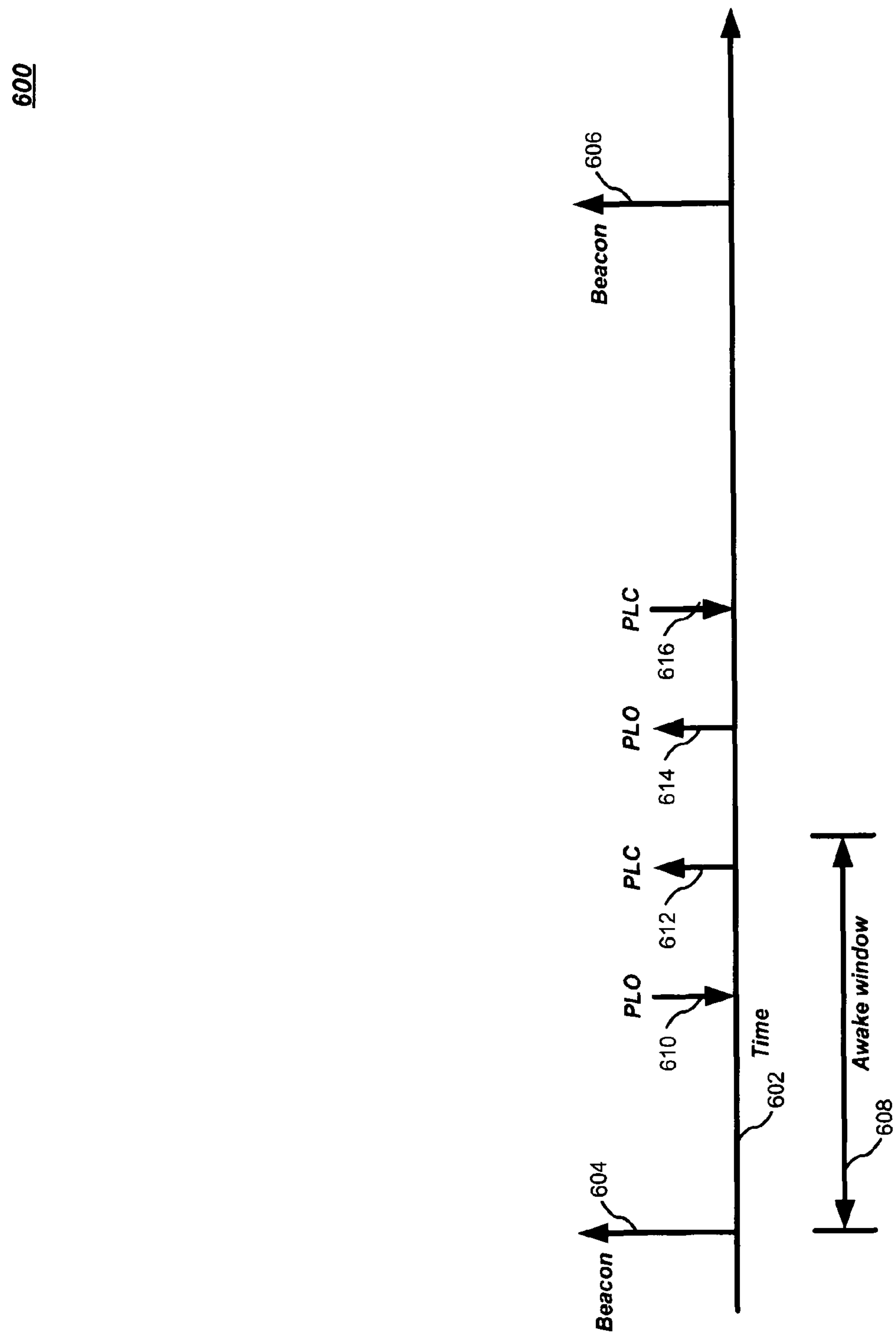

600
Beacon
606
PLC
616
PLO
614
PLC
612
PLO
610
Time
602
Beacon
604
Awake window
608

FIG. 6

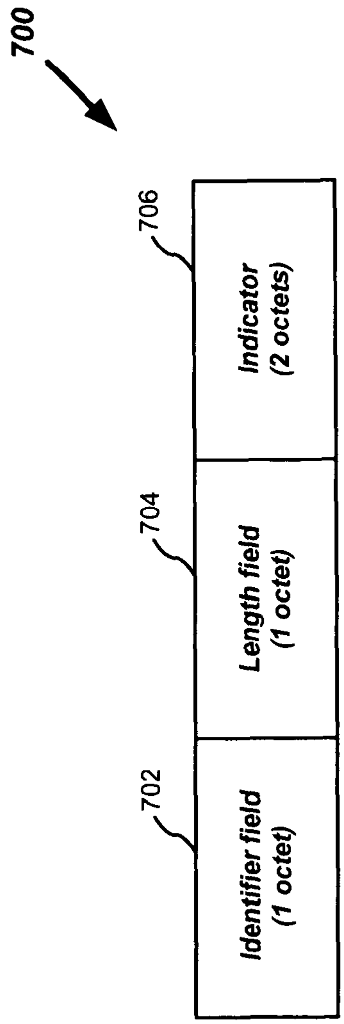

700
706
Indicator
(2 octets)
704
Length field
(1 octet)
702
Identifier field
(1 octet)

FIG. 7

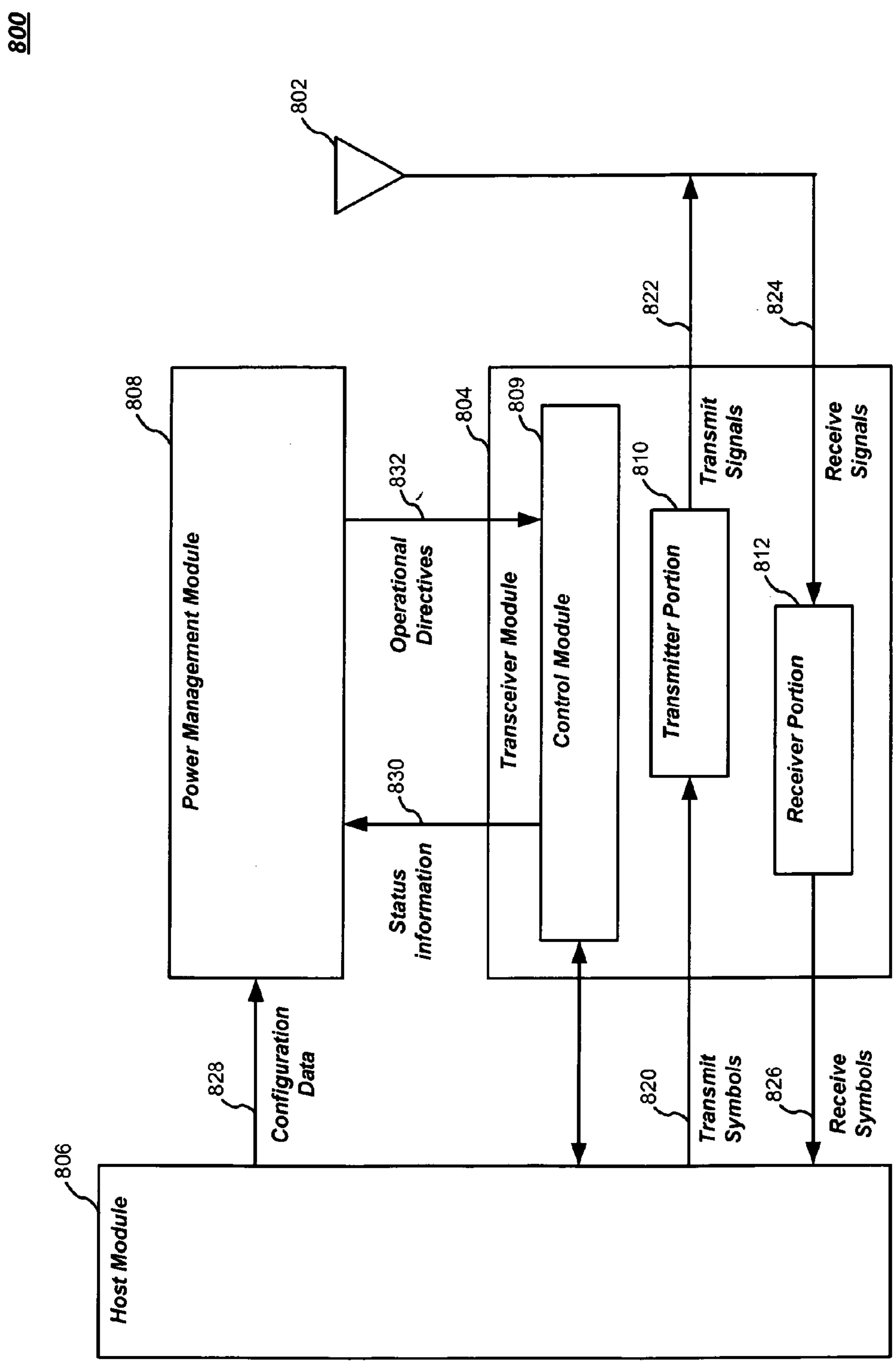

800
802
808
Power Management Module
804
Transceiver Module
809
Control Module
810
Transmitter Portion
812
Receiver Portion
806
Host Module
822
Transmit Signals
824
Receive Signals
832
Operational Directives
830
Status information
828
Configuration Data
820
Transmit Symbols
826
Receive Symbols

FIG. 8

900

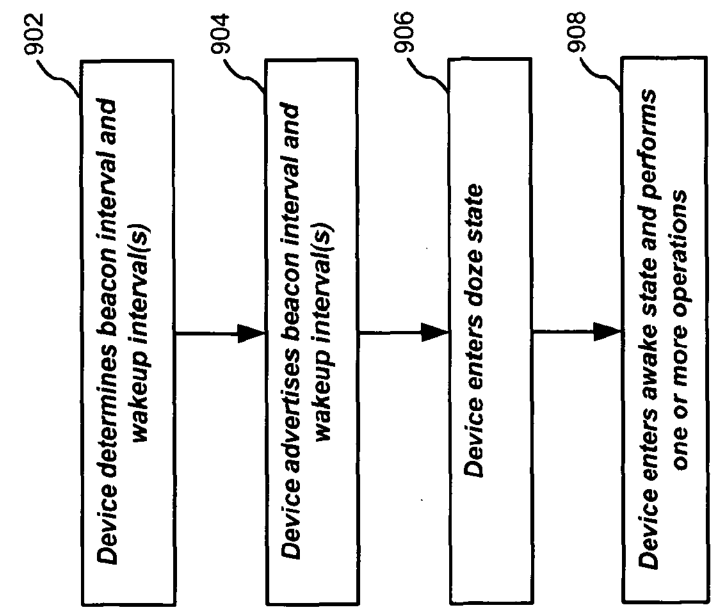

902
Device determines beacon interval and wakeup interval(s)
904
Device advertises beacon interval and wakeup interval(s)
906
Device enters doze state
908
Device enters awake state and performs one or more operations

FIG. 9

POWER MANAGEMENT FOR WIRELESS NETWORKS

CROSS-REFERENCE OF RELATED APPLICATIONS

This application is a continuation of, claims the benefit of and priority to, previously filed U.S. patent application Ser. No. 13/480,515 entitled "Power Management for Wireless Networks" filed on May 25, 2012, a continuation of U.S. patent application Ser. No. 12/317,099, entitled "Power Management for Wireless Networks" filed on Dec. 19, 2008, the subject matter of both of the above are hereby incorporated by reference in their entirety.

BACKGROUND

Wireless communications capabilities are increasingly being integrated into portable devices, including laptop computers, handheld devices (such as personal digital assistants (PDAs)), and mobile phones. The integration of such capabilities can provide users with anywhere and anytime connectivity to information resources.

Power consumption is a key feature for such devices. For instance, lower power consumption levels correspond to increased operational times between necessary battery charging sessions. As a result of this, the device user's experience may be enhanced.

Wireless mesh networks operate in accordance with a decentralized and collaborative approach. For instance, the Institute for Electrical and Electronics Engineers (IEEE) 802.11s standard provides for wireless networks composed of multiple devices (called mesh points). These devices form links among them. Moreover, information can be routed through these links in accordance with various routing protocols.

Current drafts of IEEE 802.11s (such as IEEE 802.11s Draft Standard 1.08) provide power management mechanisms that aim to conserve device power. However, these mechanisms often result in undesirable network operations.

BRIEF DESCRIPTION OF THE DRAWINGS

In the drawings, like reference numbers generally indicate identical, functionally similar, and/or structurally similar elements. The drawing in which an element first appears is indicated by the leftmost digit(s) in the reference number. The present invention will be described with reference to the accompanying drawings, wherein:

FIG. **1** is a diagram of an exemplary operational environment;

FIG. **2** is a diagram showing exemplary operational modes and states for a device;

FIG. **3** is a flow diagram showing an exemplary device operation;

FIG. **4** is a flow diagram showing an exemplary peer link establishment process;

FIG. **5** is a diagram showing exemplary device interactions;

FIG. **6** is a diagram showing a sequence of transmissions;

FIG. **7** is a diagram of an awake window information element;

FIG. **8** is a diagram of an exemplary device implementation; and

FIG. **9** is a flow diagram.

DETAILED DESCRIPTION

Embodiments provide techniques for device power management in wireless networks. For instance, an apparatus may

include a power management module, and a transceiver module. The power management module determines a beacon interval and a wakeup interval. The transceiver module to send a transmission to one or more remote devices that includes the beacon interval and the wakeup interval. The beacon interval indicates a time interval between consecutive beacon transmissions of the apparatus, and the wakeup interval indicates a time interval between when the apparatus receives two consecutive beacons from a peer device. Through the employment of such techniques efficient network operation may be advantageously achieved.

Reference throughout this specification to "one embodiment" or "an embodiment" means that a particular feature, structure, or characteristic described in connection with the embodiment is included in at least one embodiment. Thus, appearances of the phrases "in one embodiment" or "in an embodiment" in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in one or more embodiments.

FIG. **1** is a diagram of an exemplary operational environment **100** in which the techniques described herein may be employed. As shown in FIG. **1**, this environment includes multiple devices $\mathbf{102}_1$-$\mathbf{102}_{10}$. Also, FIG. **1** shows peer links $\mathbf{104}_1$-$\mathbf{104}_{17}$ among these devices.

A mesh network includes two or more mobile computing devices that have set up peer links among them. Accordingly, devices $\mathbf{102}_1$-$\mathbf{102}_{10}$ have formed a mesh network **106**. Therefore, devices $\mathbf{102}_1$-$\mathbf{102}_{10}$ are also referred to herein as mesh points (MPs) $\mathbf{102}_1$-$\mathbf{102}_{10}$.

MPs $\mathbf{102}_1$-$\mathbf{102}_{10}$ may each be various types of devices. Exemplary devices include laptop computers, desktop computers, personal digital assistants (PDAs), Ultra-Mobile personal computers (UMPCs), and Mobile Internet Devices (MIDs). However, embodiments are not limited to these device types.

Typically, mesh network operations are not determined by a central controller. Instead, such decision making is usually distributed (or collaborative) among the network's MPs. Information pertaining to such collaborative decision making may be exchanged among MPs through transmissions call beacons. During operation, the MPs independently send out beacons at their respective target beacon transmission times (TBTTs).

Moreover, MPs, may operate in accordance with various modes and states. For example, MPs may operate in either an active mode or a power saving mode. In the active mode, an MP is continually able to exchange information with other devices. However, in the power saving mode, an MP is not always available to exchange such information. Further details regarding active and power saving modes are described below with reference to FIG. **2**.

Thus, in the context of FIG. **1**, each of MPs $\mathbf{102}_1$-$\mathbf{102}_{10}$ are not active at all times. Consequently, it can be a daunting task to achieve collaboration (or distributed decision making) among MPs so that they may operate in power saving modes.

The power management schemes proposed in the IEEE 802.11s Draft Standard 1.08 are mainly based on infrastructure mode operation (in which devices communicate with each other through an access point). Also, this draft standard provides an automatic power save delivery (APSD) operation (defined in section 11A.12.6) that only works when one MP is not in power saving mode or when there is a central control entity

Further, the IEEE 802.11s Draft Standard version 1.08 requires an MP to synchronize with its peer MPs before entering a power saving mode. This draft standard provides a peer link offset synchronization scheme to accomplish such synchronization. The peer link offset synchronization scheme forbids an MP from entering the power saving mode until it has informed all of its peer MPs through unicast messages. Unicast messages are required in this scheme because broadcast messages are considered unreliable and may cause ambiguity in an MP's knowledge of power management states being employed by other MPs in the mesh network.

Embodiments provide advantages over existing techniques. For instance, embodiments provide completely distributed operation. In addition, embodiments facilitate flexible power management through two intervals: a beacon interval and a wakeup interval.

As described above, MPs may operate in accordance with various modes and states. FIG. **2** is a diagram providing examples of such modes and states. In particular, FIG. **2** shows an active mode **202**, and a power saving mode **204**.

In embodiments, an MP in power saving (PS) mode **204** may operate in one of two states. These states are an awake state **206** and a doze state **208**. In awake state **206**, the MP is fully powered, and is able to transmit or receive frames. However, in doze state **208**, the MP consumes very low power, and is not able to transmit or receive. As indicated by arrows **224** and **226**, the MP may alternate between awake state **206** and doze state **208** while operating in PS mode **204**. This alternation may be determined by specified time intervals, as well as by frame transmission and reception rules.

In active mode **202**, the MP operates in an awake state (such as awake state **206**) all the time. As indicated by arrows **220** and **222**, the MP may transition between active mode **202** and PS mode **204**. Such transitions may be based on various factors, such as user settings.

Further details regarding MP operations in PS mode **204** are now provided.

An MP in PS mode **204** (also called a "PS MP") transmits its own beacons at a pre-determined beacon interval (which are indicated by target beacon transmission times (TBTT)). Further, the PS MP wakes up (i.e., enters awake state **206** from the doze state **208**) to receive its peers' beacons and/or broadcast messages, and to also maintain synchronization and peer links. A PS MP does not have to wake up to receive every beacon from its peers. As an example, a PS MP may instead decide to receive every other beacon, every delivery traffic indication message (DTIM) beacon, or every other DTIM beacon transmitted by a peer.

The time interval between when a PS MP receives two consecutive beacons from a peer MP is referred to herein as the wakeup interval. The wakeup interval is per peer link based. Thus, a PS MP may employ multiple wakeup intervals. Moreover, each wakeup interval can be negotiated between the PS MP and the corresponding peer MP. Furthermore, the wakeup interval(s) and beacon interval(s) employed by a PS MP may be implementation dependent. For instance, wake up interval(s) and beacon interval(s) may be based on factors, such as traffic load(s) to/from peer MP(s), clock synchronization accuracy, user selection, and so forth.

In embodiments, an MP may define the length of its beacon interval and its wakeup interval(s) before it enters PS mode **204**. Also, in embodiments, the MP may inform its peer MPs of its beacon interval and target beacon transmission time (TBTT). By so doing, the MP's peers can wake up at the right time to receive the MP's beacons. Optionally, an MP's wakeup interval(s) may be negotiated with its peer MP(s). Through such negotiations, the peer MP(s) may schedule their broadcast transmission(s) to the PS MP. Further, a PS MP may also request its peer MPs to send broadcast traffic as unicast frames to itself.

In embodiments, a PS MP advertises an Awake Window in its beacon. The awake window may be indicated in an information element (IE), such as the IE of FIG. **7**. However, other forms of indication may be employed. The start of the Awake Window is measured from PS MP's TBTT. This advertised awake window indicates how long the PS MP will remain awake after sending a beacon. In contrast, a conventional PS MP returns to doze state **208** right after sending its beacon.

FIG. **3** illustrates an embodiment of a logic flow. In particular, FIG. **3** illustrates a logic flow **300**, which may be representative of the operations executed by one or more embodiments described herein. Although FIG. **3** shows a particular sequence, other sequences may be employed. Also, the depicted operations may be performed in various parallel and/or sequential combinations.

The flow of FIG. **3** involves exemplary device operations during power saving mode **204**. These operations are described with reference to a PS MP and one or more remote devices. These remote device(s) may be peer devices. Alternatively, these remote device(s) may seek to establish a peer relationship with the power saving device. The operations of FIG. **3** may occur in the context of FIG. **1**. Moreover, the PS MP and/or the remote device(s) may include features, such as those described herein with reference to FIGS. **2** and **8**.

At a block **302**, the PS MP enters awake state **206**. Upon entering awake state **206**, the PS MP sends a beacon transmission at a block **303**. This beacon provides an indication of an awake window time period. For example, this beacon may include the awake window information element described below with reference to FIG. **7**. Embodiments, however, are not limited to employing this information element.

At a block **304**, the PS MP determines whether the awake window time period has elapsed. If so, then operation proceeds to a block **350**, where the PS MP enters doze state **208**. Otherwise, performance of one or more paths may occur. For example, FIG. **3** shows a path **360** that involves the PS MP sending transmissions to a peer device, a path **370** that involves the PS MP receiving transmissions from a peer device, and a path **380** that involves the establishment of a new peer relationship. Such paths may be performed in various sequential and/or parallel orders.

FIG. **3** shows path **360** including blocks **305**-**308**. At block **305**, the PS MP indicates whether it has any buffered traffic (e.g., unicast traffic) for its peer devices. This indication may be included in a beacon transmission (such as the beacon sent at block **303**). For instance, the PS MP may make this indication by setting one or more bits in its beacon frame. For example, in the context of 802.11s networks, the PS MP may set a bit in the traffic indication map (TIM) element that matches the peer device's peer link ID.

In turn, a peer device that receives this indication of buffered traffic (e.g., buffered unicast traffic) may send the PS MP a responsive transmission (such as a trigger frame) to initiate a packet reception period. Accordingly, as indicated by a block **307**, the PS MP determines whether it has received such a responsive transmission from the peer device. If so, then operation proceeds to a block **308**. Otherwise, operation may return to block **304**.

At block **308**, the PS MP acknowledges the trigger frame and transmits its buffered traffic to the peer device. This may involve sending multiple buffered packets to the peer device.

Once the buffered traffic has been sent, the PS MP may indicate its completion of data transmission to the peer device at a block **309**. In the context of IEEE 802.11s networks, block **309** may include sending one or more data frames having an End of Service Period (EOSP) bit set. FIG. **3** shows that, following block **309**, operation may return to block **304**.

As described above, path **370** involves the PS MP receiving traffic from a peer device. FIG. **3** shows that path **370** may include blocks **310** and **312**.

A peer device having buffered traffic to send to the PS MP stays awake during the awake interval following the power saving device's target beacon transmission time (TBTT). Thus, at a block **310**, such a peer device may trigger a service period to deliver its buffered traffic to the PS MP. This may involve the peer device sending one or more triggering transmissions to the PS MP.

At a block **312**, the PS MP receives the buffered traffic from the peer device. Following this, operation may return to block **304**.

As indicated above, path **380** involves a peer connection being established between the PS MP and a remote device. FIG. **3** shows that path **380** may include blocks **330**-**332**.

At block **330**, the PS MP enters into a peer link establishment process. Details regarding an exemplary peer link establishment process are described below with reference to FIG. **4**. Following completion (e.g., successful completion or unsuccessful completion) of the peer link establishment process, operation may return to block **304**.

As described herein, embodiments may employ a peer link establishment process that may be performed after a device discovers another device that is in power saving mode **204** (e.g., a PS MP). As an example, such a process is performed at block **332** of FIG. **3**.

Accordingly, FIG. **4** is a flow diagram showing exemplary operations of a peer link establishment process. Although FIG. **4** shows a particular sequence, other sequences may be employed. Also, the depicted operations may be performed in various parallel and/or sequential combinations.

The operations in FIG. **4** are described with reference to a device (referred to as the "new device") that seeks to establish a peer relationship with a PS MP. These operations may occur in the context of FIG. **1**. Moreover the new device and/or the power saving device may include features, such as those described herein with reference to FIGS. **2** and **8**.

At a block **402** the new device may perform passive scanning to discover existing devices in a mesh network.

At a block **404**, the new device receives a beacon from the PS MP. This beacon indicates the power saving device's awake window. For example, this beacon may include an awake window information element, such as the one described below with reference to FIG. **7**. However, other awake window indications may be employed.

Based on this beacon, at a block **406**, the new device attempts to send a peer link open message to the PS MP before the end of its awake window.

As indicated by a block **408**, the PS MP determines whether it has received the peer link open message during its awake window. If so, then operations proceed to a block **410**, and the PS MP remains in the awake state until the peer link establishment process has been completed (either successfully or unsuccessfully). Otherwise, if the peer link open message is not received during the PS MP's awake window, then the peer link establishment process is unsuccessfully completed (as indicated by a block **409**).

At block **410**, the PS MP sends a peer link confirm message to the new device. Also, at a block **412**, the PS MP sends a peer link open message to the new device. In response to this peer link open message, the new device sends a peer link confirm message to the PS MP at a block **414**.

Thus, this peer link establishment procedure involves a "double handshake" of peer link open and peer link confirm messages. Accordingly, a peer link is successfully established when both devices have sent and received peer link open and confirm messages.

Without an awake window, the PS MP may immediately go back to doze state **208** after transmitting a beacon or after responding to the Peer Link Open message from the new MP.

However, to ensure that a pending double handshake can be completed, embodiments require a PS MP to stay awake (e.g., remain in awake state **206**) during its awake window, and to remain awake during a pending peer link set up process. This may advantageously promote fast and successful establishment of peer links.

FIG. **5** is a diagram **500** showing exemplary device interactions. In particular, FIG. **5** shows interactions occurring between a first mesh point **502** (which is in awake state **206**) and a second mesh point **504**. These interactions occur along a time axis **506**. Through these interactions, a peer link is established.

As described above with reference to FIG. **4**, establishment of such peer links may involve a double handshaking procedure. Accordingly, FIG. **5** shows a first handshake **520** that begins with mesh point **504** sending a peer link open message **508**. In response, mesh point **502** sends a peer link confirm message **510** to mesh point **504**. FIG. **5** further shows a second handshake **522**. This handshake involves mesh point **502** sending a peer link open message **512** to mesh point **504**, and mesh point **504** responding by sending a peer link confirm message to mesh point **502**.

FIG. **6** is a diagram **600** showing a sequence of transmissions along a time axis **602**. These transmissions are shown from the perspective of a local mesh point in awake state **206**. In this diagram, upward pointing arrows represent transmissions that are outgoing from the local mesh point, while downward pointing arrows represent transmissions that are incoming to the local mesh point.

As shown in FIG. **6**, the local mesh point transmits beacons **604** and **606**. Each of these beacons advertises an awake window. For example, beacon **604** advertises an awake window **608**. Within this window, a peer link establishment procedure begins. In particular, the local mesh point receives a peer link open (PLO) message **610** from a remote mesh point. In response, the local mesh point sends a peer link confirm (PLC) message **612** to the remote device. These two messages comprise a first handshake. As a second handshake, the local mesh point transmits a PLO message **614**. In response, a PLC message **616** is received from the remote mesh point.

Through the exchange of these messages, a peer link is established between the local mesh point and the remote mesh point. FIG. **6** shows that this peer link establishment procedure extends beyond awake window **608**. However, as described above with reference to FIG. **4**, initiation of this procedure by the remote mesh point causes the local mesh point to remain awake until the procedure is completed.

FIG. **7** is a diagram of an awake window information element (IE) **700**. As described herein, a beacon transmitted by a device in awake state **206** may include this information element. As shown in FIG. **7**, awake window IE **700** includes an identifier (ID) field **702**, a length field **704**, and an awake window indicator field **706**.

ID field **702** includes a predetermined value that identifies IE **700** as an awake window IE. Length field **704** indicates the size of IE **700**. In embodiments, the start of an awake window is measured from TBTT. Thus, awake window indicator field **706** indicates the length (or time duration) of the awake window from this starting point (the sending of a beacon).

FIG. **7** shows that identifier field **702** may have a size of one octet, length field **704** may have a size of one octet, and awake window indicator field **706** may have a size of two octets. These sizes, as well as the format of FIG. **7**, are shown for purposes of illustration, and not limitation. Accordingly, embodiments may employ other sizes and formats.

FIG. **8** is a diagram of an exemplary device implementation **800**. This implementation may be employed by devices, such as mesh points. For example, this implementation may be employed by devices $\mathbf{102}_1$-$\mathbf{102}_{10}$ of FIG. **1**. However, this implementation may be also employed in other contexts.

Implementation **800** may include various elements. For example, FIG. **8** shows implementation **800** including an antenna **802**, a transceiver module **804**, a host module **806**, and a power control module **808**. These elements may be implemented in hardware, software, firmware, or any combination thereof.

Antenna **802** provides for the exchange of wireless signals with remote devices. Although a single antenna is depicted, multiple antennas may be employed. For example, embodiments may employ one or more transmit antennas and one or more receive antennas. Alternatively or additionally, embodiments may employ multiple antennas for beamforming, and or phased-array antenna arrangements.

As shown in FIG. **8**, transceiver module **804** includes a transmitter portion **810** and a receiver portion **812**. During operation, transceiver module **804** provides an interface between antenna **802** and host module **806**. For instance, transmitter portion **810** receives symbols **820** from host module **806** and generates corresponding signals **822** for wireless transmission by antenna module **802**. This may involve operations, such as modulation, amplification, and/or filtering. However, other operations may be employed.

Conversely, receiver portion **812** obtains signals **824** received by antenna **802** and generates corresponding symbols **826**. In turn, transceiver module **804** provides symbols **826** to host module **806**. This generation of symbols **826** may involve operations, including (but not limited to) demodulation, amplification, and/or filtering.

To provide such features, transmitter portion **810** and receiver portion **812** may each include various components, such as modulators, demodulators, amplifiers, filters, buffers, upconverters, and/or downconverters. Such components may be implemented in hardware (e.g., electronics), software, or any combination thereof.

The symbols exchanged between host module **806** and transceiver module **804** may form messages or information associated with one or more protocols, and/or one or more user applications. Thus, host module **806** may perform operations corresponding to such protocol(s) and/or user application(s). Exemplary protocols include various media access control, network, transport and/or session layer protocols. Exemplary user applications include telephony, messaging, e-mail, web browsing, content (e.g., video and audio) distribution/reception, and so forth.

Signals **822** and **824** may be in various formats. For instance, these signals may be formatted for transmission in IEEE 802.11s networks. However, embodiments are not limited to these exemplary networks.

In addition to operating as an interface between host module **806** and antenna **802**, transceiver module **804** may perform various signaling, link control, and media access operations. For instance, transceiver module **804** may generate and transmit beacons (via antenna **802**), as well as exchange signaling messages (e.g., trigger messages, PLO messages, PLC messages, and so forth). These operations may be coordinated by a control module **809** within transceiver module **804**.

As shown in FIG. **8**, control module **809** is coupled to transmitter portion **810** and receiver portion **812**.

Also, FIG. **8** shows that control module **809** is coupled to host module **806** and power management module **808**. Accordingly, control module **809** may exchange information with these elements. Such information may include status information sent by control module **809** and operational directives received by host module **806** and/or power management module **808**.

Power control module **808** governs various operations of apparatus **800**. For instance, power control module **808** establishes current operational modes and states of apparatus **800** (e.g., active mode **202**, power saving mode **204**, awake state **206**, and doze state **208**). As shown in FIG. **8**, this may be carried out through operational directives **832**, which are sent to control module **809** within transceiver module **804**.

Power control module **808** may establish these modes and states based on various factors. Examples of such factors include (but are not limited to) status information **830** that it receives from transceiver module **804**, and/or configuration data **828** that it receives from host module **806**.

Configuration data **828** may include power management policies and procedures for power management module **808** to apply. Such policies and procedures may include parameters such as beacon intervals, wakeup intervals, awake windows, and so forth. In embodiments, configuration data **828** may be based (at least in part) on user settings and selections.

Status information **830** may indicate current operational status of transceiver module **804**. For instance, status information **830** may indicate pending peer establishment processes. As described herein, such processes may affect how long a device operates in awake state **206**. However, in embodiments, status information **830** may additionally or alternatively include other forms of information.

FIG. **9** illustrates a logic flow **900**, which may be representative of the operations executed by one or more embodiments described herein. Although FIG. **9** shows a particular sequence, other sequences may be employed. Also, the depicted operations may be performed in various parallel and/or sequential combinations.

These operations are described with reference to a device. This device may be a mesh point, such as one of MPs $\mathbf{102}_1$-$\mathbf{102}_{10}$ in FIG. **1**. Accordingly, this device may include the implementation of FIG. **8**. Embodiments, however, are not limited to these devices and implementations.

At a block **902**, the device determines a beacon interval and a wakeup interval.

Following this determination, the device advertises the beacon interval and wakeup interval to other devices at a block **904**. In embodiments, this advertisement is performed while the device is awake (e.g., while in active mode **202** or while in awake state **206**).

At a block **906** the device enters a doze state. From this doze state, the device enters an awake state at block **908**. While in this awake state, the device may perform various operation(s). Exemplary operations are described below with reference to FIG. **3**. For instance, the device may transmit data, receive data, and/or engage in peer establishment processes with remote devices. Embodiments, however, are not limited to these operations.

As described herein, various embodiments may be implemented using hardware elements, software elements, or any combination thereof. Examples of hardware elements may include processors, microprocessors, circuits, circuit elements (e.g., transistors, resistors, capacitors, inductors, and so forth), integrated circuits, application specific integrated circuits (ASIC), programmable logic devices (PLD), digital signal processors (DSP), field programmable gate array (FPGA), logic gates, registers, semiconductor device, chips, microchips, chip sets, and so forth.

Examples of software may include software components, programs, applications, computer programs, application programs, system programs, machine programs, operating system software, middleware, firmware, software modules, routines, subroutines, functions, methods, procedures, software interfaces, application program interfaces (API), instruction sets, computing code, computer code, code segments, computer code segments, words, values, symbols, or any combination thereof.

Some embodiments may be implemented, for example, using a machine-readable medium or article which may store an instruction or a set of instructions that, if executed by a machine, may cause the machine to perform a method and/or operations in accordance with the embodiments. Such a machine may include, for example, any suitable processing platform, computing platform, computing device, processing device, computing system, processing system, computer, processor, or the like, and may be implemented using any suitable combination of hardware and/or software.

The machine-readable medium or article may include, for example, any suitable type of memory unit, memory device, memory article, memory medium, storage device, storage article, storage medium and/or storage unit, for example, memory, removable or non-removable media, erasable or non-erasable media, writeable or re-writeable media, digital or analog media, hard disk, floppy disk, Compact Disk Read Only Memory (CD-ROM), Compact Disk Recordable (CD-R), Compact Disk Rewriteable (CD-RW), optical disk, magnetic media, magneto-optical media, removable memory cards or disks, various types of Digital Versatile Disk (DVD), a tape, a cassette, or the like. The instructions may include any suitable type of code, such as source code, compiled code, interpreted code, executable code, static code, dynamic code, encrypted code, and the like, implemented using any suitable high-level, low-level, object-oriented, visual, compiled and/or interpreted programming language.

While various embodiments of the present invention have been described above, it should be understood that they have been presented by way of example only, and not in limitation. For example, the techniques described herein are not limited to IEEE 802.11s networks.

Accordingly, it will be apparent to persons skilled in the relevant art that various changes in form and detail can be made therein without departing from the spirit and scope of the invention. Thus, the breadth and scope of the present invention should not be limited by any of the above-described exemplary embodiments, but should be defined only in accordance with the following claims and their equivalents.

The invention claimed is:

1. A mobile device, comprising:

circuitry to manage different power modes for a mesh point (MP) in a mesh network, the power modes to include an active mode and a power saving mode, the power saving mode to allow the MP to alternate between an awake state and a doze state; and

a radio frequency (RF) transceiver coupled to the circuitry to transmit electromagnetic representations of a beacon frame when the MP is in the awake state, the beacon frame to include an awake window information element comprising a size of 4 octets, the awake window information element to contain an identifier field comprising a size of 1 octet, a length field comprising a size of 1 octet, and an awake window field comprising a size of 2 octets for an awake window value to indicate a time duration of an awake window for a peer MP, the beacon frame to include a traffic indication map (TIM) element indicating whether the MP has buffered traffic for the peer MP.

2. The mobile device of claim **1**, the identifier field to comprise an identifier value to indicate the awake window information element.

3. The mobile device of claim **1**, the length field to comprise a length value to indicate a length for the awake window value.

4. The mobile device of claim **1**, the circuitry to direct the MP to enter the awake state when an awake window time period for the MP is active.

5. The mobile device of claim **1**, the beacon frame comprising a delivery traffic indication message (DTIM) beacon.

6. The mobile device of claim **1**, the RF transceiver to transmit buffered traffic during an awake window time period for the MP.

7. The mobile device of claim **1**, the circuitry to direct the MP to enter the doze state from the awake state when an awake window time period for the MP has elapsed.

8. The mobile device of claim **1**, the RF transceiver to use protocols compatible with an Institute of Electrical and Electronics Engineers (IEEE) 802.11s standard.

9. The mobile device of claim **1**, comprising at least a portion of a network interface card coupled to the circuitry.

10. An apparatus, comprising:

a power management module to direct a mesh point (MP) to enter an awake state from a doze state when in a power saving mode; and

a transceiver module to send a beacon frame to at least one peer MP when in the awake state, the beacon frame to include an awake window information element comprising a size of 4 octets, the awake window information element to contain an identifier field of 1 octet with an identifier value to indicate the awake window information element, a length field of 1 octet with a length value to indicate a length for the awake window value, and an awake window field of 2 octets with an awake window value to indicate a time duration of an awake window for the peer MP, the beacon frame to include a traffic indication map (TIM) element indicating whether the MP has buffered traffic for the peer MP.

11. The apparatus of claim **10**, the power management module to direct the MP to enter the awake state when an awake window time period for the MP is active.

12. The apparatus of claim **10**, the beacon frame comprising a delivery traffic indication message (DTIM) beacon.

13. The apparatus of claim **10**, the transceiver module to transmit buffered traffic during an awake window time period for the MP.

14. The apparatus of claim **10**, the power management module to direct the MP to enter the doze state from the awake state when an awake window time period for the MP has elapsed.

15. The apparatus of claim **10**, comprising a battery coupled to the power management module and the transceiver module.

16. The apparatus of claim **10**, the transceiver module to use protocols compatible with an Institute of Electrical and Electronics Engineers (IEEE) 802.11s standard.

17. A method, comprising:

entering an awake state from a doze state at a mesh point (MP); and

transmitting a delivery traffic indication message (DTIM) beacon when the MP is in the awake state, the DTIM beacon to include an awake window information element comprising a size of 4 octets, the awake window information element to contain an identifier field of 1 octet with an identifier value to indicate the awake window information element, a length field of 1 octet with a length value to indicate a length for the awake window value, and an awake window field of 2 octets with an awake window value to indicate a time duration of an awake window for the peer MP, the DTIM beacon to include a traffic indication map (TIM) element indicating whether the MP has buffered traffic for the peer MP.

18. The method of claim **17**, comprising entering the awake state when an awake window time period for the MP is active.

19. The method of claim **17**, comprising transmitting buffered traffic during an awake window time period for the MP.

20. The method of claim **17**, comprising entering the doze state from the awake state when an awake window time period for the MP has elapsed.

* * * * *